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IMPROVING AND VALIDATING CTAS PERFORMANCE MODELS

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Abstract

Accurate trajectory prediction is vital for Air Traffic-Control decision-support functions such as conflict detection, direct routing, and arrival metering. The Center/TRACON Automation System (CTAS) Trajectory Synthesizer uses flight plans, radar track data, and wind estimates to predict each aircraft trajectory. Among the factors that affect prediction accuracy are pilot intent and aircraft weight uncertainty, modeling errors, and radar track and wind errors. Information about pilot intent and aircraft weight is not now available to CTAS. However, one approach that can enhance prediction accuracy in the near term is to improve aircraft performance models. A cooperative effort with Boeing Aerospace was initiated to ensure that Boeing and McDonnell-Douglas aircraft are accurately represented in CTAS. A procedure has been developed to determine lift, drag, and thrust information for conversion to CTAS model format. For a climbing aircraft, differences between the CTAS and actual climb-speed profiles and weights significantly affect prediction accuracy. Hence, updated models must be validated by comparison of CTAS climb predictions with radar track data. The models can be "tuned" to minimize top-of-climb time errors using changes in thrust, takeoff weight and climb speed. A simple figure of merit has been defined for performance evaluation. The validation procedure and test implementation are presented. The results show that adjusting the nominal thrust can compensate for differences between the CTAS and actual climb schedules. The results also show that knowledge of actual aircraft weights further improves performance, especially in reducing performance "outliers".

Introduction

NASA, in cooperation with the FAA, is developing a set of decision support tools to help air-traffic managers and controllers improve flight efficiency and airspace capacity. This set of tools, known as the Center/TRACON Automation System [1] (CTAS), is designed for management of traffic within each Air Route Traffic Control Center (ARTCC) and Terminal Radar Approach Control (TRACON). At the core of CTAS is the Trajectory Synthesizer [2] (TS), which predicts a path for each aircraft from its current position more than 30 minutes ahead. Accurate trajectory prediction is vital for decision-support functions such as conflict detection, direct routing, and arrival metering.

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The TS uses aircraft flight plans, radar track data, and Rapid Update Cycle (RUC) weather-model data to compute each aircraft trajectory. Prediction of aircraft climbs, descents, and certain other flight conditions is done by integrating kinetic equations of motion. Such equations require estimates of aircraft speed profile and weight as well as thrust and drag forces (determined from aero-propulsive performance models).

A major source of trajectory prediction error is uncertainty about "pilot intent". For example, the TS assumes a particular speed schedule for each aircraft during climb; the pilot may actually climb using a different schedule. Among other factors that affect trajectory prediction accuracy are aircraft weight and engine type uncertainty, modeling errors, and radar track and wind errors. Much of the uncertainty would be reduced if each aircraft were to send flight data (position, velocity, thrust level, weight, etc.) along with its tail number (for airframe/engine identification) to the ARTCC (or directly to CTAS). Implementing such capability is planned, but its realization may be years away. Currently, engine type and aircraft takeoff weight are not included with flight-plan data. Ways of providing more specific flight-related information to

CTAS are currently under study [3]. However, one approach that can enhance prediction accuracy in the near term is to improve CTAS aero-propulsive performance models.

This paper first considers improvements to CTAS performance models and presents a procedure for validating them. To begin this task, a cooperative effort with Boeing Aerospace was initiated to ensure that Boeing and McDonnell-Douglas aircraft are accurately represented in CTAS. CTAS researchers now have access to Boeing and McDonnell-Douglas aircraft performance software (INFLT and OPAL), which can simulate complete climb-cruise-descent trajectories for most Boeing and McDonnell-Douglas aircraft. This software is generally used by airlines for flight planning purposes - at NASA Ames it has been used to update and improve CTAS aero-propulsive models [4]. A procedure was developed to obtain drag and thrust information for conversion to the CTAS model format. Validation of the CTAS model for the B737-300 will be described in the next section.

Having accurate aircraft models is a necessary, but far from sufficient condition for CTAS to create accurate trajectory predictions. For example, a difference between the climb-speed profile used by CTAS and the profile actually flown can significantly affect the accuracy of the time to top-of-climb (TOC) estimate for a departing aircraft. Present-day decision-support systems like CTAS receive no information from the aircraft flight deck to assist the trajectory-prediction task. Lacking real-time weight and speed schedule data, CTAS uses aircraft-specific nominal values. Climb trajectories for jets are calculated with a level acceleration at 10000 ft to a nominal climb CAS (calibrated airspeed), followed by a constant-CAS climb, with transition to constant Mach at an *altitude* chosen to stay within the aircraft performance envelope. Hence, CTAS performance must be evaluated by comparison of its trajectory predictions with tracking data.

The paper attempts to evaluate CTAS climb-trajectory accuracy by comparing its predictions of TOC time to "truth" values determined from recorded altitude tracking data. A simple figure of merit (FoM), based on top-of-climb time error, has been chosen for performance evaluation. The evaluation was performed using two days of recorded departure data from the Dallas - Ft. Worth Airport (DFW). The DFW TRACON and the surrounding Ft. Worth ARTCC (ZFW) are CTAS field-test sites. Included in the data set were 470 American Airlines (AAL) MD-80 aircraft. DFW is an American Airlines Hub; MD-80s account for over 50% of all AAL aircraft there each day. To support the study, AAL supplied takeoff weight data for all its departing aircraft for the two days. The CTAS performance evaluations presented in this paper are for MD-80 departures.

The test plan consisted of running CTAS with the recorded data for five cases. In the first, the nominal CTAS thrust scaling (2.0 engines), climb CAS (280 kn) and takeoff weight (132300 lb) were used to obtain "baseline" FoM mean and standard deviation values for the 136 MD-80 aircraft that had uninterrupted climbs to cruise altitude. The other four cases were designed to evaluate the effects on performance by "tuning" thrust and climb CAS, and by giving CTAS the actual takeoff weight for each aircraft in the sample. The test results presented in this paper show that adjusting the nominal thrust can compensate for differences in the CTAS and actual climb schedules. The results also show that knowledge of actual aircraft weights further improves CTAS performance, especially by reducing the variation in performance.

The paper proceeds with a section on the CTAS aero-propulsive performance-modeling problem, which includes the models necessary to represent the ZFW traffic mix. Following sections describe how the TS computes a climb trajectory, and how the CTAS climb schedule affects TOC error. Then a section discusses the performance evaluation test plan, followed by a presentation of performance results achieved to date. A final section summarizes the modeling effort and suggests a plan for extension of the work.

Performance Modeling

There are more than 2000 different aircraft types in the National Airspace System when all types and within-type variations are taken into account. Currently, there are only about 400 distinguishable FAA Type-Designator (TD) codes. When an aircraft enters CTAS-equipped airspace, its TD is determined from an FAA-supplied flight plan. This TD becomes the key for choosing the aero-propulsive models for trajectory calculation. If the TD provides insufficient differentiation for choosing the proper drag and/or thrust model, some prediction error should be expected. For example, some aircraft types are equipped with different engines. (It would seem a simple matter for the FAA to expand the TD codes or add tail numbers to the flight plan in order to reduce model uncertainty.) A recent two-day tabulation of flights in ZFW [5] showed that the top ten aircraft types accounted for 1310 of 2295 flights (57%); the top 20 accounted for 71% of the total. Table 1 shows the top ten, with the possible model ambiguity indicated in the column labeled A.

<u>Model Validation</u>

It should be emphasized that even with its inventory including all 400 FAA Type Designations, CTAS will not be able to match the exact airframe and engine model for every aircraft type. Nevertheless, the goal is to obtain the best possible representations, with the flexibility to adapt to expanded type designations and/or data-linked flight information. The CTAS "Aircraft_Specific_Model_Data" file defines each aircraft type and its flight envelope. Sample entries for the McDonnell-Douglas MD-80 and Boeing B737-300 aircraft are shown in Table 2. Here the lines defining drag and thrust models "point" to files that have recently been validated with Boeing performance data. It should be noted that file entries for aircraft without airframe or engine manufacturer data are referenced to the most appropriate model. Notice that the "effective number of engines" line of the file allows scaling of engine thrust. The "default ascent CAS" line allows changes in climb speed.

Table 1 Aircraft types in ZFW in a two-day period.

TD	Model	No.	Cum. %	A*
MD80	MD-82/83	357	15.6	T
B733	B737-300	186	23.7	T
SF34	SF-340	183	31.7	
B722	B727-200	126	37.2	T
FK10	F-100	94	41.1	
B752	B757-200	87	44.9	D, T
B732	B737-200	79	48.3	T
E120	EMB-120	76	50.8	
DC9	DC-9	72	54.1	T
B735	B737-500	50	57.1	

*D = Drag model; T = Thrust model

Table 2 CTAS reference data for the MD-80 and B737-300 aircraft.

AIRCRAFT NAME	MD-80	B737-300
MANUFACTURER	DOUGLAS	BOEING
ENGINE NAME	JT8D-217	CFM56-3C-1
NUMBER OF ENGINES	2	2
FAA (OR CTAS INTERNAL) ACID	MD8	B733
GROSS WING AREA (FT^2)	1209	980
MAXIMUM TAKEOFF WEIGHT (LB)	147000	124500
OPERATING WEIGHT EMPTY (LB)	79600	72000
TYPICAL DESCENT WEIGHT (LB)	110000	100000
AIRFRAME DRAG MODEL	MD80	B733
ENGINE THRUST MODEL	JT8D-217	CFM56-3C-1
ENGINE TYPE	JET	JET
DESCENT DRAG SCALE FACTOR	1.0	1.0
EFFECTIVE NUMBER OF ENGINES	2.0	2.0
MAXIMUM MACH	0.84	0.82
MAXIMUM CRUISE MACH	0.82	0.78
MINIMUM CAS (KN)	220	220
MAXIMUM CAS (KN)	340	340
MINIMUM CRUISE CAS (KN)	240	230
MAXIMUM CRUISE CAS (KN)	320	320
DEFAULT DESCENT CAS (KN)	280	280
DEFAULT ASCENT CAS (KN)	280	280

Having the INFLT and OPAL software at Ames makes it possible to update CTAS aero-propulsive models for most Boeing and McDonnell-Douglas aircraft. Drag and thrust information extracted from performance runs is converted to the CTAS model format. An example comparison of INFLT and (updated) CTAS versions of a B737-300 climb to 33000 ft is shown in Fig. 1. For INFLT, takeoff weight was 120000 lb; fuel burn to TOC was 2960 lb. The speed profile was to climb at 250 kn (CAS) to 10000 ft, accelerate to 310 kn and climb at that CAS, with transition to a constant Mach 0.76 climb to TOC. The "stand-alone" TS was utilized to create a CTAS trajectory from 11000 - 33000 ft. The TS was initialized with the INFLT state values at 11000 ft (the software had been modified to use the same Mach transition value). Currently, a CTAS aircraft burns no fuel; therefore the CTAS weight was set to the average of INFLT weights between 11000 ft and the TOC. The results of Fig. 1 show virtually identical INFLT and CTAS climb trajectories, with very close agreement in thrust and drag.

The CTAS Climb Trajectory

Calculation of aircraft altitude in climb (or descent) is based on the following equation of motion[2]:

$$\dot{V}_t \cong g(T - D)/W - g\gamma_a - \gamma_a V_t (dV_w/dh) \qquad (1)$$

where V_t is true airspeed, g is acceleration of gravity, V_w is wind speed, γ_a is aerodynamic flight-path angle, and h is altitude; T is thrust, D is drag, and W is aircraft weight. The dot indicates a derivative with respect to time. For a climbing aircraft, Eq. (1) can be rewritten to represent altitude rate using

$$\gamma_a \approx \dot{h}/V_t \text{ and } \dot{V}_t = (dV_t/dh)\,\dot{h}$$

$$\text{to obtain } \dot{h} = g(T - D)/WF, \qquad (2)$$

$$\text{where } F = g/V_t + (dV_t/dh) + (dV_w/dh).$$

The altitude is determined by integrating Eq. (2). For constant CAS (or Mach) climbs, the quantities V_t and (dV_t/dh) are computed along constant CAS (or Mach) lines. This is a simpler calculation than that required for accelerating to the nominal CAS while climbing, since there is no need to integrate Eq. (1) to determine true airspeed.

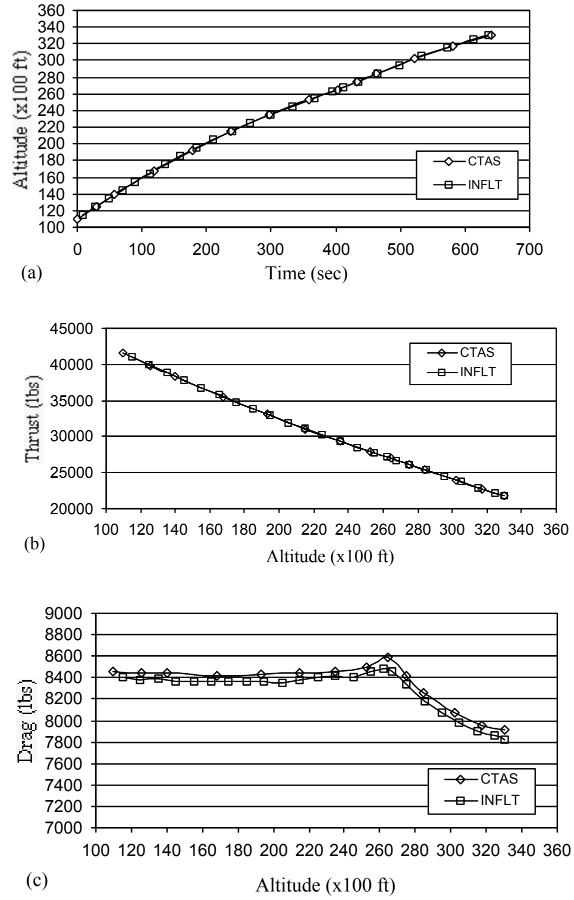

Fig. 1 INFLT – CTAS performance comparisons for a B737-300 aircraft: (a) trajectory, (b) thrust, (c) drag.

In the model comparison described in the previous section, the climb-speed schedules for the stand-alone TS and INFLT trajectories were identical. In normal operation, however, the current TS creates a climb trajectory for jets by joining a constant CAS climb to a transition *altitude* with a constant Mach climb above that altitude to top-of-climb. The CAS chosen is a nominal value recommended by the aircraft manufacturer. The constant Mach value is whatever the Mach is at the transition altitude. A trajectory prediction is made for each aircraft at each radar track hit (track hits are about 12 sec apart). If the track altitude is below the transition value, and the CTAS estimate of CAS (derived from groundspeed and wind estimates), is less than the nominal CAS value, the first part of the trajectory will consist of a level acceleration to the nominal CAS.

Lacking real-time information from the aircraft flight deck about its scheduled CAS-Mach transition, CTAS relies on a relatively simple algorithm to determine a transition altitude that maintains performance within "the envelope". It works as follows: At 35000 ft, a CAS value corresponding to 0.91 of the maximum Mach is calculated; a similar calculation is made at 10000 ft; linear interpolation between these altitude-CAS pairs with the nominal climb CAS determines the transition altitude. While the Mach transition value used by the TS to predict a climb trajectory usually does not match the actual Mach transition, the difference in time to TOC can be reduced on average, for a given aircraft type, by scaling thrust. This is illustrated in Fig. 2 for the B737-300, where the effect of "normal" TS operation, for a constant CAS climb of 310 kn, shows a large error in TOC time, compared to the 310/0.76 transition simulation of Fig. 1. Scaling the thrust to 2.2 engines ($K_T = 2.2$) is seen to greatly reduce the error.

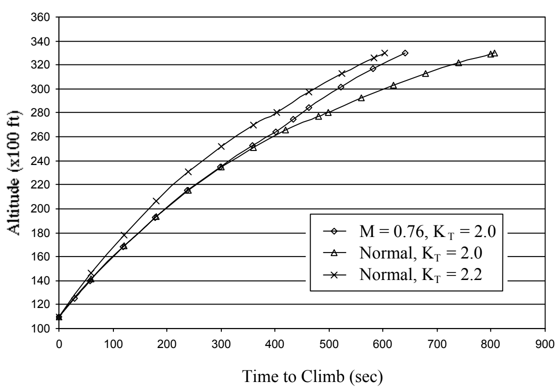

Fig. 2 Comparison of B737-300 trajectories with different climb schedules and thrust.

Performance Evaluation

In the model comparison described in an earlier section, errors due to uncertainty in pilot intent, aircraft weight, winds, etc. were not present. Hence, once an aero-propulsive model has been updated and validated, the effects of these uncertainties must be evaluated in the field. In this study, the evaluation is performed for climb trajectories, and the metric is based on TOC time error. Shown in Fig. 3 is a typical CTAS prediction from 11000 ft to top-of-climb at 33000 ft. Also shown is the Mode-C altitude record; the time difference (in min) between the trajectories at top-of-climb is defined as the TOC time error. If a CTAS prediction for the same aircraft is observed, say every 2000 ft, a typical TOC error record might look like that shown in Fig. 4.

A useful figure of merit for evaluating performance is defined as

$$\mathrm{FoM} = [1/(h_f - h_s)^3] \int_{h_s}^{h_f} (h - h_s)\,|e|\,dh \qquad (3)$$

where h is altitude, e is the TOC time error, and the subscripts s and f refer to the altitude of the starting prediction and final (TOC) point, respectively.

An idealization of the typical error record is shown as a straight line in Fig. 4. Here the metric is easily shown to be $\mathrm{FoM} = e_s / 6(h_f - h_s)$. Notice that FoM is proportional to the slope of the idealized error. With perfect flight information, each prediction would match the altitude record exactly, and the slope would be zero! The metric of Eq. (3) seems to work well, regardless of the shape of the error curve. It should be noted that the metric has been scaled so that for an idealized error record like that of Fig. 4, with h_s = 12000 ft and h_f = 30000 ft, a value of FoM = 1 would correspond to a starting prediction error of e_s = 3 min.

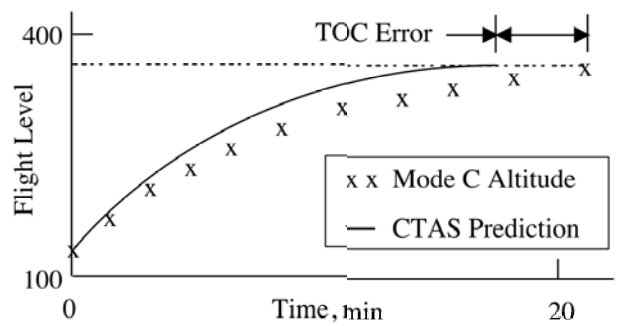

Fig. 3 Typical CTAS prediction and actual track.

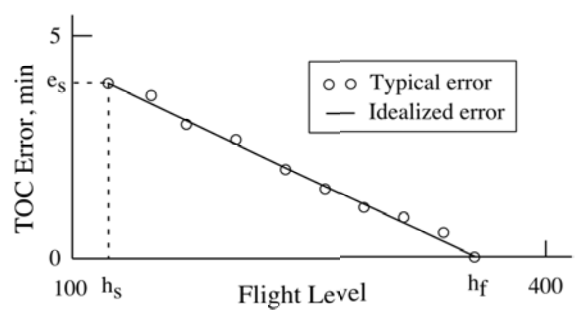

Fig. 4 Typical and idealized TOC error plots.

Test Implementation

To implement the evaluation procedure, software has been added to CTAS to detect aircraft as they depart from DFW. This software has the option to capture predicted climb trajectories by either aircraft type or airline. The altitude at which the recording process will begin can be selected, as well as the altitude interval between trajectory recordings. During the test, all radar tracking data are also recorded. When data collection is complete, predictions for each aircraft can be compared to the TOC from the actual altitude record, and an FoM value calculated from TOC time error vs altitude data. The analyses are to be performed for each aircraft that has an uninterrupted climb to TOC. An aircraft that receives an altitude flight-plan amendment during its climb will be removed from the analysis. In this case, a non-negligible time interval might have occured before the change was received by CTAS. An aircraft would also be removed when it was obvious that a temporary-altitude clearance had been issued (without an amendment).

The evaluation was performed by running CTAS using Host tracking data and flight plans, and RUC weather data recorded over two days in November 1999 for the ZFW airspace. An arrangement was made with American Airlines (AAL) to obtain data on all its departing flights for the period. These data included tail numbers and takeoff weights for 520 aircraft on Thursday the 18th, and 275 aircraft on the Friday the 19th. Of these, there were a total of 470 MD-80 aircraft (309 on the 18th, 161 on the 19th). Since the MD-80 accounts for over 50% of all AAL departures each day, it was decided to focus the analysis on that aircraft. Having tail numbers allows within-type identification. For example, of the 470 MD-80 aircraft, 421 were the MD-82 model (PW JT8D-217 engine), and 49 were the MD-83 model (PW JT8D-219 engine). The –219 engine produces about 10% more thrust than the –217 engine. Although the CTAS MD-80 thrust model is based on the PW JT8D-217 engine, the –219 can be modeled simply by thrust scaling.

As demonstrated earlier, differences between the CTAS and actual climb-speed schedules can significantly affect TOC errors in time and position. It was decided to look at the climb schedules actually flown by the MD-80 aircraft in the study. The test software was modified to record the CAS/Mach values that initiated each trajectory prediction. These values are estimated at each track hit from groundspeed and heading, using RUC data to subtract the wind components and correct for air density and compressibility effects. The CAS/Mach climb profiles, averaged for 1000 ft altitude intervals, are shown as solid lines in Figs. 5 (a) and (b). Vertical bars indicate the standard deviations of either CAS or Mach at each altitude. In Fig. 5(a), the "average" aircraft is seen to be accelerating while climbing to a maximum CAS of 300 kn at approximately 20000 ft. CAS is then held constant until 25000 ft after which it begins to decrease. Figure 5(b) shows Mach increasing to approximately 0.75 by 30000 ft. Not many of the flights climbed all the way to 35000 ft: for most flights the TOC was 31000 ft. Data like that shown in Fig. 5 can be used to more realistically model climb schedules to include acceleration during climb. As expected, the standard deviations decrease as the aircraft reach higher altitudes where the difference between minimum and maximum speed decreases.

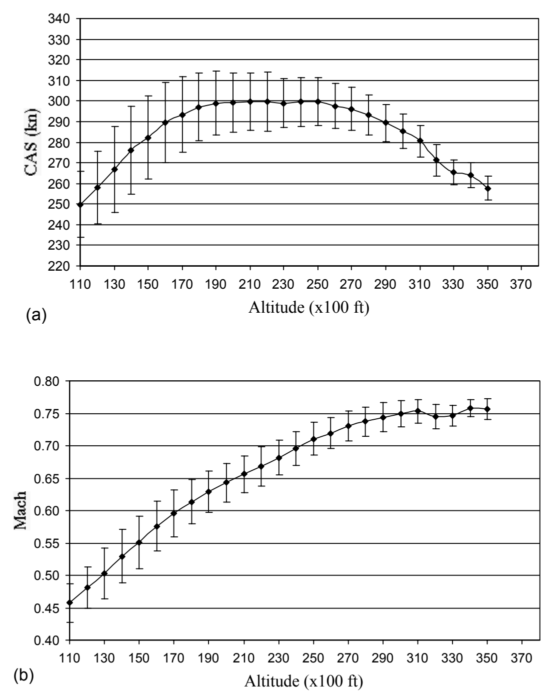

Fig. 5 Mean MD-80 climb profiles for 249 aircraft recorded November 1999: (a) CAS, (b) Mach.

The test plan evolved somewhat as the study progressed. The final plan consisted of operating CTAS with the recorded data for five cases. In the first, the nominal CTAS thrust scaling (2.0 engines), climb CAS (280 kn) and takeoff weight (132300 lb) were used to obtain "baseline" FoM mean and root mean-squared (rms) values for the 136 MD-80 aircraft that had uninterrupted climbs to cruise altitude. The other four cases were designed to evaluate the effects on performance by "tuning" thrust and climb CAS, and by giving CTAS the actual takeoff weight for each aircraft in the sample. Based on the data presented in Fig. 5, in an attempt to better match actual climbs, one case was run with an increase of nominal climb CAS to 285 kn. To accommodate the AAL-supplied weight data, two cases were run with the TS modified to use an individual weight for each aircraft instead of the CTAS default value. The cases run were:

1. Thrust scaled at 2.00 engines; climb CAS set at 280 kn; weight at 132300 lb.
2. Thrust scaled at 2.15 engines; climb CAS set at 280 kn; weight at 132300 lb.
3. Thrust scaled at 2.15 engines; climb CAS set at 285 kn; weight at 132300 lb.
4. Thrust scaled at 2.15 engines; climb CAS set at 280 kn; AAL takeoff weights.
5. Thrust scaled at 2.20 engines; climb CAS set at 280 kn; AAL takeoff weights.

CTAS trajectory predictions for each AAL MD-80 departure were recorded every 1000 ft from 11000 ft to top-of-climb. Each set of trajectories includes altitude and planview time histories, predicted TOC time and position, and initial CAS and Mach. Only those that represented uninterrupted climbs to cruise altitude were selected for analysis. Of the two-day total of 470 departing MD-80 aircraft, only 247 climbed without formal flight-plan amendments; of those, only 136 were free of temporary-altitude holds. When an aircraft deviates from its flight plan, CTAS cannot predict accurate trajectories until it is notified of a change in plan, or until enough track hits have been received to enable its built-in heuristics to modify the plan. The sample for the results presented in the next section was comprised of the 128 MD-82 and 8 MD-83 aircraft that had "clean" climbs.

Performance Results

Performance results for the MD-80 cases outlined above are presented in Table 3. In addition to calculating the FoM for each aircraft in the sample, each run was sorted by whether its TOC predictions were consistently earlier or later than the actual top-of-climb for the aircraft. (A negative TOC error is "early"; a positive error is "late".) If <u>all</u> predictions for an aircraft were early, the run would be categorized as early; if <u>all</u> were late, the run would be categorized as late. Runs that had both early and late predictions were categorized as "both". The bar chart of Fig. 6 shows the early-late distribution for all cases. This sorting procedure served as a guide during the test for adjusting thrust scaling for the JT8D-217 engine. Achieving about equal early and late runs, with a large number in the "both" category might be expected to result in the best "tuning" of CTAS performance. The results show that the influence of errors in climb schedules, etc. on trajectory accuracy can be reduced by modifying thrust. Modifying weight or drag could yield similar results (see Eq. (2)).

Case 1 (the "baseline") clearly shows that trajectories computed with the 2.00 thrust scale factor result in most predictions arriving at the top-of-climb later than the actual Mode-C altitude records indicated. The FoM values for Case 1 are also the largest of all the cases. Increasing the thrust scaling to 2.15 in Case 2 moves the early-late mix in the right direction, and significantly reduces the FoM mean and rms values. It was thought that increasing the climb CAS to 285 kn might help the TS better model the AAL climb profiles

Table 3 Summary of CTAS (MD-80) performance for Nov. 18-19 1999.

Case	1	2	3	4	5
Weight (lb)	132300	132300	132300	AAL Closeout	AAL Closeout
Engine Scaling Factor	2.00	2.15	2.15	2.15	2.20
Climb CAS (kn)	280	280	285	280	280
Late	104	43	50	54	35
Early	9	35	35	25	40
Both	23	58	51	57	61
Total	136	136	136	136	136
FoM: Mean / RMS	2.41 / 3.27	1.04 / 1.40	1.14 / 1.59	0.80 / 0.99	0.70 / 0.92

summarized in Fig. 5. However, the results for Case 3 show more late runs and higher FoM values than for Case 2. The reason for this probably lies in the MD-80 performance characteristics. OPAL simulation data show that, for a –219-equipped MD-80, a climb CAS of 280 kn will sustain an equal or higher climb rate than 285 kn for altitudes above 15000 ft.

When CTAS uses the AAL-supplied takeoff weight for each aircraft, the mean and rms FoM values are further reduced, as shown by the results for Cases 4 and 5. It should be noted that the mean weight of the sample was 132329 lb (only 29 lb greater than the CTAS nominal weight); the sample standard deviation was 9882 lb. The minimum and maximum weights were 98273 and 152029 lb, respectively. Knowledge of correct aircraft weights not only reduces the mean FoM value, but more importantly (from a controller's point of view), reduces the FoM "outliers" significantly. This is clearly evident in the chart of Fig. 7, where it is seen that all FoM values between 7-12 occur for Case 1, while there are no values beyond FoM = 4 for Case 5. These results confirm the potential benefits to be derived from including weight in the flight-plan message. A slight increase in thrust scaling, to 2.20, in Case 5 is seen to yield about equal early and late runs,

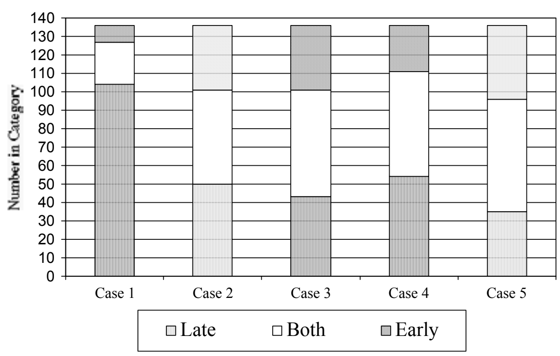

Fig. 6 Number of aircraft in each test case.

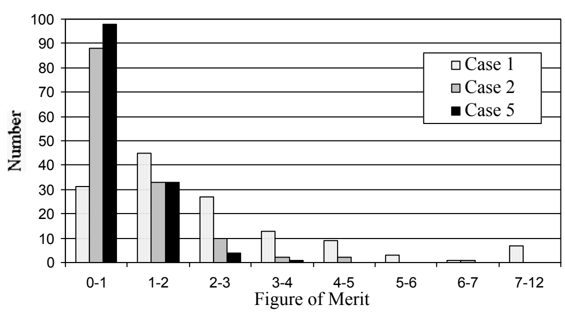

Fig. 7 FoM distribution for three cases.

and the lowest mean value for the performance figure of merit. This case would seem to represent the best tuning of CTAS MD-80 parameters for DFW departures at the present time.

Concluding Remarks

The problems inherent in a CTAS (or any DST) trajectory prediction have been reviewed. In addition to uncertainty of pilot intent, the largest sources of prediction error are weight uncertainty, aero-propulsive model errors, and track and wind errors. Improvement of drag and thrust models for many Boeing and McDonnell-Douglas aircraft has been accomplished through the use of company performance software. It is planned to pursue similar efforts with other manufacturers, as well as to add new Boeing models as they become available.

A plan for validating the model improvements by running CTAS with recorded traffic and weather data to compare predicted climb trajectories with actual track data for DFW departures has been presented. This effort takes advantage of extended flight-plan data from AAL that include takeoff weights and tail numbers. A simple metric for performance evaluation, based on TOC time error, has been defined. A similar evaluation could, of course, be performed with descent trajectories.

The evaluation was performed on a sample consisting of 136 AAL MD-80 aircraft departing from DFW. It was shown that the influence of errors in climb schedules, etc. on CTAS trajectory predictions can be reduced by modifying thrust. It is also shown that when CTAS has the correct takeoff weight for each aircraft, TOC prediction-error "outliers" are fewer in number. Not only are the FoM mean values reduced, but, more importantly, knowledge of correct aircraft weights lowers FoM rms values significantly. These results confirm the potential benefits to be derived from including weight (and other parameters) in the FAA flight plan. Also, other methods will be investigated that can provide more real-time flight data to CTAS.

With the testing procedure in place, it should be feasible to select other popular aircraft types for similar performance evaluations in order to "tune" CTAS trajectory predictions for those aircraft. While it is not yet possible for CTAS to receive information about climb schedule from the flight deck (or the Host computer), it may be worthwhile to design a more sophisticated algorithm for predicting a climb trajectory (and the CAS/Mach transition). The testing procedure can also serve to evaluate any such algorithm and compare the results to those presented in this paper.

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References

[1] Erzberger, H, Davis, T.J., Green, S.M.: “Design of Center-TRACON Automation System,” Proceedings of the AGARD Guidance and Control Panel 56th Symposium on Machine Intelligence in Air-Traffic Management, Berlin, GDR, 1993, pp 52-1 - 14.

[2] Slattery, R.A., Zhao, Y.: “En-Route Trajectory Synthesis for Air Traffic Control Automation,” Proceedings of the 1995 American Control Conference, Seattle WA, June 21-23, 1995.

[3] Coppenbarger, R. A.: “En-route Climb Trajectory Prediction Enhancement Using Airline Flight-Planning Information,” AIAA 99-4147, Guidance Navigation, and Control Conference, Portland OR, August 9-11, 1999.

[4] Warren, A., Ebrahimi, Y.: “CTAS Performance Model Validation,” Boeing Aerospace Final Report, RTO-28, NAS2-98001, January 2000.

[5] Paglione, M.M. et al: “Trajectory Prediction Accuracy Report: User Request Evaluation Tool (URET)/Center-TRACON Automation System (CTAS),” Federal Aviation Administration Technical Note DOT/FAA/CT-TN99/10.